DECLARATION

I declare that this thesis entitled "Energy Management For A Series Hybrid Electric Vehicle (HEV)" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ____________________________

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Date : 19 JUNE 2012

ABSTRACT

The studies for hybrid electrical vehicle (HEV) have attracted considerable attention because of the necessity of developing alternative methods to generate energy for vehicles due to limited fuel based energy, global warming and exhaust emission limits in the last century. HEV incorporates internal composition engine, electric machines and power electronic equipments. In this study, overview of HEVs with a focus on hybrid configurations and energy management strategies are presented. This project is to be carried out by perform a demonstration of small scaled hardware that will used remote control (RC) parts as components to this project. First phase of the project will be focusing on software that will monitoring the speed of DC motor and perform a close loop that will estimate the energy requirement in certain condition. While the second phase of the project will be focusing on hardware development integrating with energy management software. The ratings of the battery and engine and the power output that will be delivered by each source under the expected condition will be considered in this paper. In this paper, the software and hardware that will be used and integrated will mention. An in house series hybrid electric vehicle will develop and in other word this paper presents the small scale of Series Hybrid Electric Vehicle (SHEV).

ABSTRAK

Kajian untuk kenderaan elektrik hybrid (HEV) telah menarik perhatian kerana keperluan membangunkan kaedah alternatif untuk menjana tenaga bagi kenderaan kerana tenaga bahan api terhad, pemanasan global dan had pelepasan ekzos di abad yang lalu. HEV menggabungkan enjin komposisi dalaman mesin elektrik dan perlatan elektronik kuasa. Dalam kajian ini, gambaran HEV dengan fokus pada konfigurasi hibrid dan strategi pengurusan tenaga dibentangkan. Projek ini akan dijalankan dengan melaksanakan demosntrasi perkakasan berskala kecil. Fasa pertama projek ini akan memberi tumpuan kepada perisian yang akan memantau kelajuan motor DC dan melaksanakan gelung rapat yang akan menggarkan keperluan tenaga dalam keadaan tertentu. Manakala, fasa kedua projek ini akan memberi tumpuan kepada pembangunan menyepadukan perkakasan dengan perisian pengurusan tenaga. Penilaian bateri dan enjin dan keluaran kuasa yang akan disampaikan oleh setiap sumber di bawah kedaan yang dijangka akan dipertimbangkan dalam kertas kerja ini. Dalam kertas ini, perisian dan perkakasan yang akan digunakan dan bersepadu akan disebut. Kenderaan Hibrid Siri akan dibangunkan dalam kata lain kertas kerja ini menbentangkan skala kecil Siri Hibrid Elektrik Kenderaan

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LIST OF ABBREVIATIONS

HEVs	-	Hybrid Electric Vehicle
SHEVs	-	Series Hybrid Electric Vehicle
PHEVs	-	Parallel Hybrid Electric Vehicle
DC	-	Direct Current

CHAPTER I

INTRODUCTION

1.1 Background of Project

In urban area, due to the beneficial effect on environment, electric and hybrid vehicles are an important factor for improvement of traffic and more particular for a healthier environment. We are quite rapidly reaching the end of the cheap oil era. Therefore the need for alternative energy source is growing and the price competition of alternatives against oil is becoming more and more realistic. Electric and electric hybrid vehicles are offering the best possibility for the use of new energy sources because electricity can result from a transformation with high efficiency of these sources and is always used with the highest possible efficiency in systems with electric drives or components. Some basic considerations about electric and hybrid vehicles today are presented together with the infrastructure developments [2].

A hybrid electric vehicle is propelled with stored energy from a battery or flywheel, plus energy produced by burning fuel in an engine. The cost of the energy consumed, as well as the quantity of air pollutants released, can be reduced by optimizing the ratings of the battery and engine and the power output that will be delivered by each source under the expected driving conditions. Life-cycle cost can be minimized by running the engine at a constant speed and power, and by avoiding deep discharges of the battery.

The main issue for HEV design is controlling the energy transfer from sources to the loads with minimum loss of energy which depends on the driving cycles. HEVs include more electrical apparatus such as electric machines, power electronics, electronic continuously variable transmissions, embedded powertrain controllers, advanced energy storage devices and energy converters as compared to the conventional internal combustion engine vehicles (ICEVs). The powertrain configuration of HEV can be divided into three types, series, parallel and series-parallel. The series hybrid is the simplest kind of HEV [3]. Its engine mechanical output is first converted into electricity using a generator. The converted electricity either charges the battery or can bypass the battery to propel the wheels via the same electric motor and mechanical transmission.

The cost of energy consumed as well as the quantity of air pollutants released can be reduced by optimizing the ratings of the battery and engine and the power output that will be delivered by each source under the expected driving conditions [4]. Therefore, the study of the energy management of hybrid electric vehicle is compulsory to upgrade the performance of the battery and also performance of the battery also performance of the vehicles.

1.2 Problem Statement

Growing concerns about oil prices and environmental protection have forced the automotive industry to accelerate the pace of the development of hybrid electric and fuel cell vehicles for mass marketing. Hybrid electric vehicles (HEVs) seem to be the most economically viable solution so far and probably for the next decade [1], [2]. As hybrid electric vehicles (HEVs) are gaining more popularity in the market, the rule of the energy management system in the hybrid drivetrain is escalating [8]. Performance of the hybrid electric vehicle always focuses on sources, the powerful of the battery and also the internal combustion engine (ICE). However, the more power of the source, the more expensive the vehicle. So, to overcome this problem, an energy management on this hybrid electric vehicle has to propose so that energy that was produced either by the battery or internal combustion engine can be managed. For example, the cost of the energy consumed as well as the quantity of air pollutants released can be reduced by optimizing the ratings of the battery and engine and the power output that will delivered by each source under the expected driving conditions.

1.3 Objectives

The objectives of this project are:

1. To design and develop an energy management system of series HEV.
2. To develop an in-house HEV unit in series configuration, electronic system and demonstrate the operation.

1,4 Scope of Project

This project is about an energy management system of series HEVs that is focused on software development include programming the microcontroller and hardware development to show the series HEVs configuration system and demonstrate the energy management. A Radio Controlled Nitro Car is used as an in house model of a vehicle and electronic systems are designed to show the energy management in series HEVs.

1.5 Project Outline

This project consists of five chapters including this chapter. The content of each chapter can be outlined as follows:

Chapter 2 provides a literature review, background, previous research done by other researchers in the same area and relevant issues to Series Hybrid Electric Vehicles and also the energy management. The principle designs of a hybrid electric vehicle have been considered especially on series configuration and some studies of the components have been mentioned in this chapter.

Chapter 3 describes a broad description of the research methodology in this project. This chapter begins with description of theoretical studies focusing on energy management of series hybrid electric vehicle methods including the use of the RC nitro car compartment. This chapter state the three phase of the methods in order to create the energy management of series hybrid electric vehicle. The software and circuit diagram of the electronic system including the integration between the software and hardware have been showed in this chapter.

Chapter 4 presents the result and discussion of this project based on the energy management created by integration between the software and hardware. The movement of the car recovered in two conditions, accelerating and decelerating where presented by electronic component and shows the series configuration hybrid electric vehicle. The result of this project recovered only in that two conditions and discussion of each condition have followed.

Chapter 5 provides a general conclusion based on this project status. The improvement for further studies on energy management of series hybrid electric vehicle is established. Future works for completing the study are highlighted. Other research opportunities for future work are presented.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter describes some literature related on Hybrid Electric Vehicle (HEV) have conducts by others researcher related in this project. This project require a full understanding about the Hybrid Electric Vehicle especially in series configuration system, so overview from previous study really help in understanding the concept and idea of the whole project.

Nowadays, HEVs become more popular among giant company and has increase in the level of research and development being conducted into the field in order to yield greater performance benefits. There are number of papers investigating areas for improvement and providing possible solutions as well as looking at the current state available technologies in order optimize performance.

2.2 Principle design of a Hybrid Electric Vehicle

There are several previous studies conducted into the current state of HEVs to give a general idea of what is presently achievable. Two examples are “Electric and Electric Hybrid Vehicle Technology A Survey” [3] and the “Ultracapacitors For Electric, Hybrid and Fuel Cell Vehicles” [4], both papers give a useful overview on the principles design of a HEVs as well as the different configurations and components involved. Some useful information about different configuration of HEVs and list of battery options with advantages and disadvantages as well as a table of characteristic such as specific energy, specific power and energy density [3]. There is also a brief discussion of possible motor selections. The second paper [4] covers similar studies with some focus on the background of the problem. This project generally focused on the series configuration system, this paper [5] said that the series hybrid is a combination of energy sources. The traction is obtained by only one central electric motor or by wheel hub motors. The total energy source results from the combination of two or more energy sources. The rated power of the engine-generator group can be designed on very different ways depending on the applications characteristics.

Besides that, the second paper [5] said that one of the alternative energy storage methods is ultracapacitors. In its discussion, based on nowadays technology, available HEVs made more relevant due to the increased market penetration over those 10 years. This provides a useful insight for car manufacturers in adopting hybrid technology as well as their preferred architectures and component choices.

After several years, extensive research has been done on PHEVs and HEVs. As it has two sources of energy for example engine and battery, some researchers have presented a few energy management strategies and optimized them using various optimization techniques. Dominik Karbowski [12] has investigated about the control strategy for transmission of parallel PHEV using global optimization technique based on Bellman principle. Its main objective was to reduce the losses in engine, motor, and battery. Then the results were compared with the default control strategy of PSAT for different distances travelled by PHEV. While, paper study by Aymeric and

Sylvain [13], they used DIRECT algorithm to obtain some optimized parameters for rule-based control strategy for transmission of parallel PHEV. They also analyzed the impact of distance travelled by PHEV on these parameters. Both papers showed that drive cycle and distance travelled impact their results significantly.

2.3 System Configuration

The definition of the HEVs is so general that it anticipates future technologies of energy sources [5]. As proposed by Technical Committee 69 (Electric Road Vehicles) of the International Electrotechnical Commission, a HEVs is a vehicle in which propulsion energy is available from two or more kinds or types of energy stores, sources or converters, and at least one of them can deliver electrical energy. Based on this general definition, there are many types of HEVs, such as the engine and battery, battery and fuel cell, battery and capacitor, battery and flywheel and battery and battery hybrids. However, the above definition is not well accepted. Ordinary people have already born in mind that a HEVs is simply a vehicle having both an engine and an electric motor. To avoid confusing readers or customers, specialists also prefer not using the HEVs to represent a vehicle adopting energy source combinations other than the engine and battery hybrid. For example, they prefer to call a battery and fuel cell HEVs simply a fuel cell EV. As we prefer general perception to lose definition, the term HEVs in this paper refers only to the vehicle adopting both the engine and electric motor for the drive train, while the engine and battery hybrid is the energy source. Traditionally, HEVs were classified into two basic kinds, series and parallel. Recently, with the introduction of some HEVs offering the features of both the series and parallel hybrids, the classification has been extended to three kinds, series, parallel and series–parallel. In the year 2000, it is interesting to note that some newly introduced HEVs cannot be classified into these three kinds. Hereby, HEVs are newly classified into four kinds:

1. Series hybrid
2. Parallel hybrid
3. Series–Parallel hybrid
4. Complex hybrid

Series hybrid electric vehicles (SHEV) involve internal combustion engine (ICE), generator, battery packs, rectifier, capacitors, converters and electric motors as shown in Fig. 2.1. Based on papers [18], [19], [20], [21], [22], [23],[24], SHEV has no mechanical connections between ICE and wheels.

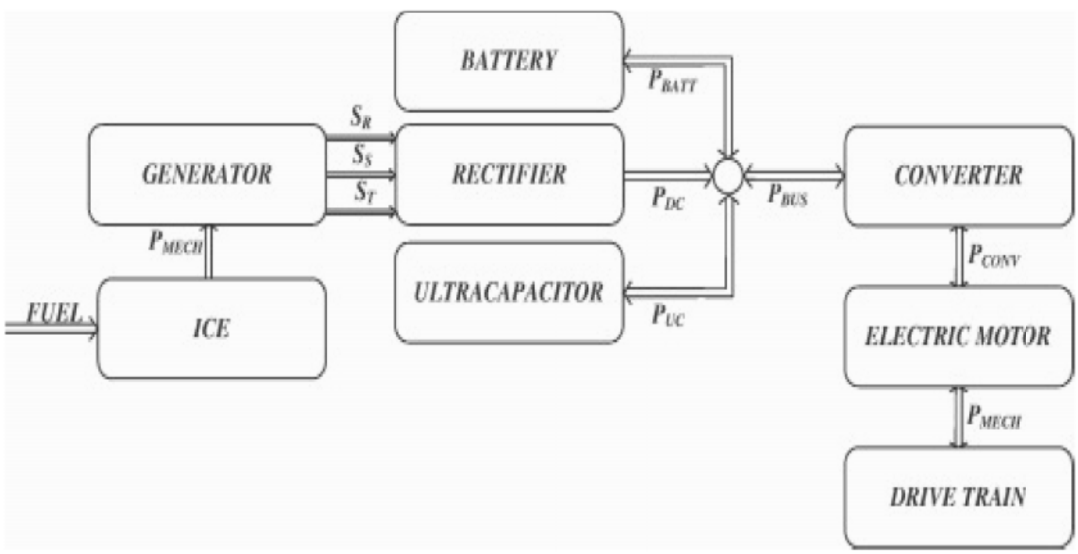

Figure 2.1: The power flow of SHEV powertrain [18].

ICE is turned off when the battery packs feed the system in urban driving. Significant amount of energy is supplied from the regenerative braking and the down slope driving. Ultracapacitors are added to the system to extend the lifecycle and the efficiency of the battery. ICE is turned on when the battery energy is low in the country driving. If the power demand of electric motor is the less than output power of generator, the remaining power is used to charge ultracapacitor banks and battery pack. If the power demand of motor is higher than the output power of the generator, the required energy is supplied from ultracapacitor banks and battery pack.

Therefore, engine operates at its maximum efficiency point so the fuel efficiency improves and the carbon emission is less than the other vehicle configurations. It is applied to the commercial vehicles with the improvement of SHEV configurations. SHEV applications include TEMSA – Avenue Hybrid bus, Mercedes – Citaro bus and

Table 1: Benefits of the series hybrid configuration [26].

Features	Optimized efficient power plant	Fast "black box" service exchange possible
	Modular power plant possibilities	Long operational life
	Optimized efficient traction drive line	Mature well proven technology
	Engine down sizing	Excellent transient response
	Space packaging advantages	Zero emission operation possible
Disadvantages	Larger traction drive system	
	Careful design algorithms a prerequisite	
	Multiple energy conversions	
Vehicles systems/applications	TEMSA Avenue Hybrid	Tesla ultra light rail
	Orion VII	Conventional light rail
	Wrightbus electrocity	New Tesla buses

2.3.2 Parallel hybrid electric vehicles (PHEV)

In PHEV, both the mechanical power output and the electrical power output are connected in parallel to drive the transmission as shown in Fig. 3. There are various control strategies used for parallel configuration. In the most common strategy, ICE is basically always in on mode and operates at almost constant power output at maximum efficiency point.

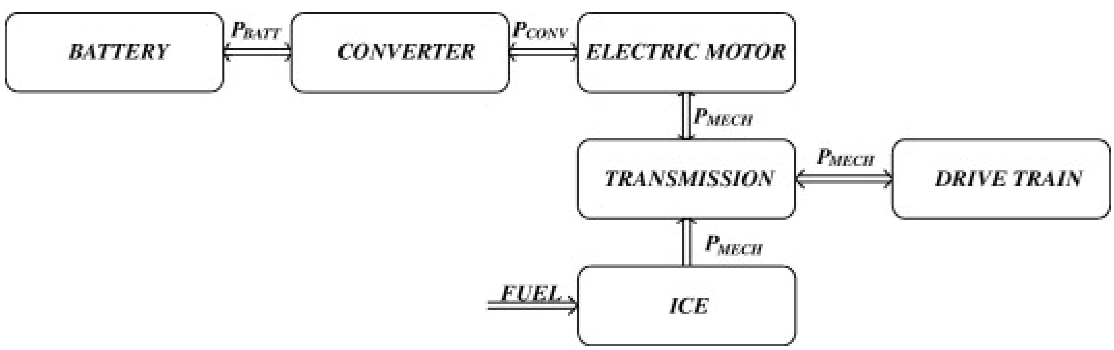

Fig. 2.2: The power flow of parallel HEV powertrain.

If the power requested from transmission is higher than the output power of ICE, the electric motor is turned on, ICE and electric motor supply power to the transmission. If the power requested from transmission is less than the output power of the ICE, the remaining power is used for charging the battery packs. In this configuration, regenerative braking power on a down slope driving is used to charge the battery. Insight model introduced by Honda is a specific implementation of parallel HEV (PHEV). Other examples for PHEV applications are Ford Escape Hybrid SUV and Lexus Hybrid SUV. Benefits of the parallel hybrid configuration are given in Table 3[26].

Table 2: Benefits of the parallel hybrid configurations [26].

Features	Economic gain at high cost
	Retarder option but at complexity risk
	Zero emission operation possible

Disadvantages	Expensive system
	Control complexity
	Careful design algorithms a prerequisite
	High voltages needed for efficiency
	Complex space packaging
	Hino HIMR
Vehicles systems/applications	Bus/heavy truck market

Table 3: A general comparison of SHEV and PHEV Powertrain [26].

Architecture	System voltage	Typical power requirement (kW)	Electric fraction (%)	Relative fuel economy gain (%)
Parallel Configuration	14 V, 42 V, 144 V, 300 V	3–40	5–20	5–40
Series Configuration	216 V, 274 V, 300 V, 350 V, 550 V, 900 V	>50	100	>75

2.3.3 **Combination of parallel and series HEVs**

Combination of parallel and series hybrid configurations into a single package is quickly becoming the standard in passenger vehicle hybridization [27]. As the name implies the combination hybrid configuration is neither fully parallel nor series configuration. Fig. 4 shows the essential of the combination architecture.

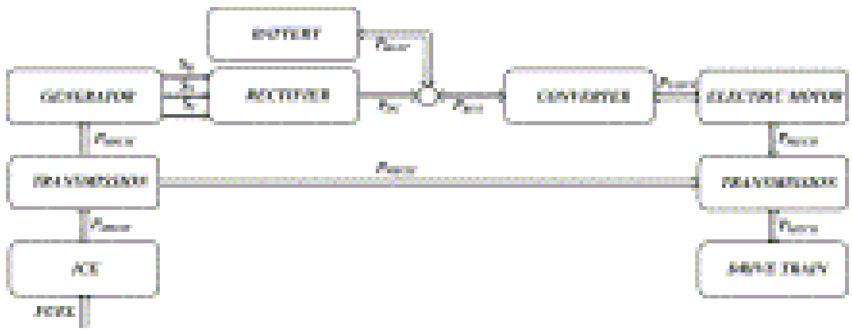

Figure 2.3: The combination of parallel and series hybrid configurations.

In the series-parallel hybrid, the configuration incorporates the features of both the series and parallel HEVs, but involves an additional mechanical link compared with the series hybrid and also an additional generator compared with the parallel hybrid. Although possessing the advantageous features of both the series and parallel HEVs, the series-parallel HEV is relatively more complicated and costly. Nevertheless, with the advances in control and manufacturing technologies, some modern HEVs prefer to adopt this system.

2.3.4 Complex hybrid system

As reflected by its name, this system involves a complex configuration which cannot be classified into the above three kinds. As shown in Fig. 1, the complex hybrid seems to be similar to the series-parallel hybrid, since the generator and electric motor are both electric machinery. However, the key difference is due to the bidirectional power flow of the electric motor in the complex hybrid and the unidirectional power flow of the generator in the series-parallel hybrid. This bidirectional power flow can allow for versatile operating modes, especially the three propulsion power (due to the engine and two electric motors) operating mode, which cannot be offered by the series-parallel hybrid. Similar to the series-parallel HEV, the complex hybrid suffers from higher complexity and costliness. Nevertheless, some newly introduced HEVs adopt this system for dual axle propulsion.

2.4 Series Hybrid Electric Vehicle (SHEV) studies.

This project will be more focusing on the series system and the study and research about series configuration hybrid vehicle is very important so that this project can proceed. However, the scope of this project will be smaller compare to other research that will only required a small scale of an in house energy management. Based on paper [3], series hybrids are more suited to large scale applications such as busses and military vehicles, since the traction motor is the only torque source in the vehicle and as such needs to be a considerable size in order to propel the vehicle at a reasonable speed [3]. The parallel configuration is better applied to smaller passenger vehicles since it utilities two torque sources in parallel (the ICE and electric motor) to the final drive simultaneously, meaning the motor can be sized smaller and such as the drivetrain itself will take up significantly less space [3]. The third configuration is the series-parallel architecture preferred by Toyota for its Hybrid Synergy Drive which combines the benefits of the series and parallel configurations through use of a planetary gear input that acts as a power splitting device. This technology will transfer engine power to the drive train and generator as necessary [8]. The downside of this method is the added cost and complexity resulting from the additional generator and planetary gearset [3].

In this project, energy management will be considered for a Series Hybrid Electric Vehicle. So, this paper [6] have discussed more about the energy management in the component have use. This paper said that, during the SHEV automobile working process, it often happens that energies from two or more sources superimpose. The main purpose of the correct matching of SHEV powertrain is determine the operating characteristics of the engine and its power distribution and energy balance with the energy storage device. By controlling the working status of various energy sources, the energy conversion efficiency can be improved, the loss due to energy transmission can be reduced, and ultimately the energy can be utilized in a maximum way for SHEVs. The general control strategy for SHEVs is developed normally based on the parameters such as battery, the driver's accelerator pedal position, the wheel speed and the average power of the driving wheel and then the engine and electric motor generate the corresponding torque to meet the requirements of the driving torque for the driving wheel. Commonly used control strategies include "thermostat" and "power follower" , where the power follower strategy are described as follows, when the battery SOC is greater than the upper limit of SOCmax, the engine stops working, but when the power demand of vehicle is too large, the engine needs to be restarted, when the battery SOC is less than the lower limit SOCmin, the engine needs to get to work, when the engine works, its power output should not only follow the changes of the power demand of the vehicle, but keep the battery SOC around the middle value of its working range, while he engine is working, its output power should not be too small or too large in order to ensure high efficiency.

2.5 Electric Motor

Based on this paper [3], the electric propulsion system consists of three main parts that are electric motor, a power electronic converter and its controller. At first, author said that DC motor drives have the proper characteristic for fraction application and was popularly used a couple decades ago. However, DC motor drives low efficiency, the need of maintenance and low reliability. Relate with my project, I will certainly use DC motor because this project prefers to develop an in house energy management of Hybrid Electric vehicle and it just a small scale component. With the coming era of power electronics and digital microprocessor control technology, other advanced motor drives are mature to replace the dc motor drive in traction applications. At present, permanent magnet brushless dc (BLDC) motors, induction motors (IM), and switched reluctance motors (SRM) are considered to be the most likely candidates for the vehicle propulsion application.

The different traction motor options available are also focus on number of papers [3], [4], [6]. Their author said that specifically there are three main choices, permanent magnet brushless DC motors, induction motors and witched reluctance motors. Generally no clear conclusions are given. In fact, the reader can make a choice depending on the application. The three traction motor have their advantages and disadvantages. Permanent magnet machines typically have a high power density and efficiency, low maintenance and easy to control but have a short constant power range impacting on the ability of the vehicle to use the motor cruise [1], [3]. Induction machines can be rated for high power levels and are relatively cheap and readily available. However they suffer from rotor copper losses which reduce efficiency over PM motors and will stall above a certain critical speed [3], [6]. Switched reluctance machines have a large extended power region, are different at high speeds, are fault tolerant and have a high power density, however they suffer from torque ripple and high acoustic noise, although this can be controlled and require a complicated controller [3], [4], [7]. The general consensus of the literature is that all three are appropriate for vehicle applications and have their respective advantages, although some comparisons could be made in ADVISOR.

2.6 Motors and generators

Generators make DC current, and batteries need DC for charging. Generators were used in automobiles until around 1970, when alternators became more practical (due to the availability